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ABSTRACT

The effect of perceptual speed on performance and paper-and-pencil measures of spatial ability is examined. Perceptual speed is defined as speed in comparing figures or symbols, scanning to find figures or symbols, or carrying out other very simple tasks involving visual perception. It was hypothesized that perceptual speed would have more influence on the paper-and-pencil measures because of the similarity of the tasks, and that the influence would be different for males and females. Seven hundred males and 700 females were administered a battery of tests including a measure of perceptual speed and performance measures of spatial ability from the Johnson O'Connor Research Foundation aptitude test battery, and paper-and-pencil measures of spatial ability from the Kit of Factor-Referenced Cognitive Tests. The paper-and-pencil measures had higher correlations with the measure of perceptual speed for both males and females. Factor analysis showed that inclusion of a perceptual speed factor did not affect the factor patterns for males and females, but did cause some changes in the factor loadings for females. (Author/RL)

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THE INFLUENCE OF PERCEPTUAL SPEED ON PERFORMANCE VERSUS PAPER-AND-PENCIL MEASURES OF SPATIAL ABILITY

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The Influence of Perceptual Speed on Performance versus Paper-and-Pencil Measures of Spatial Ability

Richard Bowker and Richard S. Trafton

SUMMARY: The study examined the effect of Perceptual Speed on performance and paper-and-pencil measures of spatial ability. It was hypothesized that Perceptual Speed would have more influence on the paper-and-pencil measures because of the similarity of the tasks, and that the influence would be different for males and females. Seven hundred males and 700 females were administered a battery of tests including a measure of perceptual speed and performance measures of spatial ability from the Johnson O'Connor Research Foundation aptitude test battery, and paper-and-pencil measures of spatial ability from the Kit of Factor-Referenced Cognitive Tests. The paper-and-pencil measures had higher correlations with the measure of Perceptual Speed for both males and females. Factor analysis showed that inclusion of a Perceptual Speed factor did not affect the factor patterns for males and females, but did cause some changes in the factor loadings for females.

Introduction

Spatial ability is measured both by paper-and-pencil tests and by performance tasks. Paper-and-pencil tests are often multiple-choice; in them, subjects are asked to work out mentally some task (e.g. comparison, rotation) involving drawings of two- or three- dimensional objects, and to choose which of a number of alternatives represents their answer. Performance tests typically are timed, and require the subject to actually carry out some task (e.g. assembly) on an object.

Paper-and-pencil tests are generally easier to administer and more suitable for group testing than performance tests. In the case of spatial ability, however, it is possible that the very different methods of measurement might result in very different ability estimates for individuals, and very different interpretations of the spatial factor or factors. In particular, the nature of paper-and-pencil testing may cause problems for the measurement of spatial ability.

This paper examines data concerning one factor that may have different effects on performance vs. paper-and-pencil measures of spatial ability: Perceptual Speed. Perceptual Speed (P) has been defined as:

> Speed in comparing figures or symbols, scanning to find figures or symbols, or carrying out other very simple tasks involving visual perception. (Ekstrom, French, Harman, & Dermen, 1976)

Perceptual Speed is typically measured by simple number or figure matching and identification tasks. These tasks would appear to have more in common

with paper-and-pencil spatial tasks than performance spatial tasks. The paper-and-pencil tests are predominantly visual and often require comparing features of drawings; performance tests in addition to the visual component usually require manipulation of the object. Perceptual Speed has been hypothesized to be related to certain aspects of spatial ability (Ekstrom et al., 1976), but research in this area has typically been carried out with paper-and-pencil measures.

A complicating factor in an analysis of perceptual speed and spatial ability is that both factors show clear sex differences. Males tend to be superior in spatial ability (McGee, 1979), and females tend to score higher on measures of perceptual speed (Super & Crites, 1962). For this reason, males and females will be studied separately in this paper, to see if there is a difference in the effects of Perceptual Speed based on sex.

Method

Materials

The paper-and-pencil measures of spatial ability were drawn from the Kit of Factor-Referenced Cognitive Tests (Ekstrom et al., 1976). Since more than one factor appears to be involved in the general term "spatial ability", tests were chosen to represent several of these factors. The tests in the Kit are all in two equivalent parts. Because of time constraints, only the first half of each test was used. (Descriptions of the tests are drawn from Ekstrom et al.) The tests used in the study were:

1. Shape Memory. A measure of Visual Memory (MV). The subject is asked to identify those irregular forms that were previously seen in the same orientation on a study page. Reliability = .52.

2. Form Board. A measure of Visualization (VZ). Each item presents five shaded drawings of pieces, some or all of which can be put together to form a figure in outline form. The task is to indicate which of the pieces, when fitted together, would form the outline. Reliability = .68.

3. Surface Development. A measure of Visualization. Drawings are presented of solid forms that could be made with paper or sheet metal. With each drawing there is a diagram showing how a piece of paper might be cut and folded so as to make the solid form. Dotted lines show where the paper is folded. One part of the diagram is marked to correspond to a marked surface in the drawing. The subject is to indicate which lettered edges in the drawing correspond to numbered edges or dotted lines in the diagram. Reliability = .83.

4. Cube comparison. A measure of Spatial Orientation (S). Each item presents two drawings of a cube. Assuming no cube can have two faces alike, the subject is to indicate which items present drawings that can be of the same cube and which present drawings that cannot be of the same cube. Reliability = .63.

5. Map Planning. A measure of Spatial Scanning (SS). The subject sees diagrammatic sections representing city maps. The streets are blocked at various points by barriers represented by circles. The subject must plan routes between given points in such a way that no roadblocks need to be crossed. The task is to find the shortest available route as quickly as possible. Reliability = .63.

6. Hidden Figures. A measure of Flexibility of Closure (CF). The task is to decide which of five geometrical figures is embedded in a complex pattern. The test has some variance on Factors S and VZ. Reliability = .68.

The performance measures of spatial ability were drawn from the aptitude test battery of the Johnson O'Connor Research Foundation. They are:

1. Wiggly Block. A rectangular block of wood is made up of several irregularly curved pieces. The block is disassembled, and the subject is asked to reassemble it as quickly as possible. Three different blocks of increasing complexity (six, nine, and twelve pieces) are used. Since the score is based on completion times, lower scores indicate superior performance, and a negative correlation indicates a positive relationship. To avoid confusion, all signs for the Wiggly Block test will be changed in this paper. Also, since the time scores on the Wiggly Block produce a skewed distribution, the scores were subjected to a natural log transformation before being used in the correlational analyses. Reliability = .73.

2. Paper Folding. A variation of the Paper Folding test in the Kit of Factor-Referenced Cognitive Tests, where it is a measure of VZ. For each item successive drawings illustrate two or three folds made in a square sheet of paper. The final drawing of the folded paper shows where a hole is punched in it. The subject places chips on a square diagram to indicate where the holes would be when the punched sheet is fully reopened. Reliability = .83.

The measure of perceptual speed, Number Checking, is also drawn from the O'Connor test battery. Two numbers are printed to the left and right of a line. The numbers become progressively longer. The subject is to place a check on the line if the numbers are the same. Reliability = .90.

Subjects

Subjects were drawn from the population of examinees tested by Johnson O'Connor Research Foundation, an aptitude assessment organization. A total sample of 700 males and 700 females, ranging in age from 13 to 61, received the battery of tests. Several geographic regions were represented by the sample.

Procedure

The paper-and-pencil spatial tests and the Number Checking test were administered by tape in small group settings. The subjects read the instructions contained in the Kit of Factor-Referenced Cognitive Tests for each of the spatial tests. The Wiggly Block and Paper Folding tests were given individually by trained test administrators.

Results

Sex Differences

Table 1 gives the adjusted mean scores for each sex on the various tests. Because there was a wide age range among the subjects, and because some of the tests show age differences in performance, age and age squared were covaried in calculating means. The results are similar to previous findings. Females

score higher on the Perceptual Speed test; males score higher on most of the spatial tests. The exceptions are Hidden Figures, in which the difference is non-significant, and Shape Memory, on which females score slightly higher than males.

Correlations

Table 2 gives the correlations between Number Checking and the spatial tests. The correlations in all cases have been corrected for unreliability (Nunnally, 1978, p.219). The size of the correlations are as hypothesized: the individually-administered performance tests, Wiggly Block and Paper Folding, have very low correlations with Number Checking. The paper-and-pencil spatial tests have uniformly higher correlations, both for males and females. In general, the correlations for males tend to be slightly higher than those for females.

Factor Analysis

For the factor analyses, scores on one additional test were added to the data set. The test was Object Observation, a short-term memory test drawn from the O'Connor battery. In it, the subject is shown a photograph of twenty common objects, followed by a series of photographs in which the objects were removed, replaced, or moved. The subject is to point out the changes. The reliability of this test is .62. The test was added to the analyses in order to help define a memory factor.

The correlations were factor analyzed using Rao's canonical factor model. A scree test suggested that five factors would adequately describe the data for both sexes. Several different rotations of the factor matrix were made to approximate simple structure. The best result was obtained with an Oblimin rotation (delta = -.50). This solution accounted for 83% of the common variance for males and 87% of the common variance for females.

1. Males

Table 3 gives the factor pattern and factor correlations for all the tests except Number Checking. Table 4 gives the same information with Number Checking added.

In Table 3, the first factor is clearly a Visualization one, with high loadings for Form Board, Wiggly Block, and Paper Folding. This factor accounts for 67% of the variance. The second factor, with high loadings for Cube Comparison and Map Planning, appears to be Spatial Orientation. The third factor is Visual Memory, with a high loading for the Shape Memory test. The fourth factor appears to be another Visualization factor. It has high loadings for Surface Development, Paper Folding, and Hidden Figures, but low loadings for Form Board and Wiggly Block. Object Observation has the highest loading on the fifth factor; this factor may be termed Eidetic Memory.

The inclusion of Number Checking scores causes a clear Perceptual Speed factor to emerge (factor two in Table 4), with moderate loadings for Hidden Figures and Map Planning. The remaining five factors are changed relatively little from those in Table 3, except for the order of their appearance; in particular, the two Visualization factors switch places, with the factor composed of Paper Folding, Surface Development, and Hidden Figures now accounting for most of the variance (63%).

Table 1

Sex Differences on Perceptual Speed and Spatial Tests

Test	Adjusted Mean[1]		p
	Males	Females	
Number Checking	154.01	162.28	<.001
Wiggly Block[2]	2.45	3.23	<.001
Paper Folding	19.31	15.83	<.001
Shape Memory	11.52	11.95	.002
Form Board	9.53	8.06	<.001
Cube Comparison	11.71	10.79	<.001
Map Planning	10.57	9.99	.004
Surface Development	17.45	14.78	<.001
Hidden Figures	5.64	5.80	.452

[1] Age and Age[2] covaried. N: Males=674; Females=579
[2] Scores based on completion time. Lower scores indicate better performance.

Table 2

Correlations between Number Checking and Measures of Spatial Ability

Test	Males		Females	
	r[1]	p	r[1]	p
Wiggly Block	.06	.11	.01	.79
Paper Folding	.03	.43	.08	.04
Shape Memory	.17	<.001	.18	<.001
Form Board	.19	<.001	.18	<.001
Cube Comparision	.22	<.001	.16	<.001
Map Planning	.38	<.001	.27	<.001
Surface Development	.20	<.001	.11	.004
Hidden Figures	.33	<.001	.34	<.001

N: males=700, females=700

[1]correlations corrected for unreliability

Table 3

Factor Pat[illegible] and Factor Correlations
of Spatial Tests for Ma[illegible] with Perceptual Speed Factor Excluded

Factor Pattern

Variable	Factor 1	2	3	4	5	h^2
Object Observation	.01	.07	.13	-.01	.65	.53
Paper Folding	.37	-.06	-.01	.52	.22	.77
Shape Memory	.01	-.03	.71	.01	.09	.55
Form Board	.66	.29	.13	.08	-.09	.80
Cube Comparison	.10	.78	-.04	.01	.10	.72
Map Planning	.02	.52	.17	.31	.01	.64
Surface Development	.12	.15	.02	.69	.10	.80
Hidden Figures	.07	.12	.14	.44	-.09	.36
Wiggly Block	.57	.01	-.03	.17	.30	.71
% of variance	66.8	10.5	8.9	7.6	6.1	86.8 total

Factor Correlations

	Factor	1	2	3	4	5
	1	1.00	.43	.18	.62	.37
	2	.43	1.00	.25	.49	.17
Factor	3	.18	.25	1.00	.33	.31
	4	.62	.49	.33	1.00	.20
	5	.37	.17	.31	.20	1.00

Table 4

Factor Pattern and Factor Correlations of
Spatial Tests for Males with Perceptual Speed Factor Included

Factor Pattern

Variable	Factor 1	2	3	4	5	6	h^2
Number Checking	-.02	.74	.03	-.01	.05	.01	.58
Object Observation	-.01	-.01	.18	-.02	.06	.53	.40
Paper Folding	.57	-.15	.04	.22	.08	.25	.79
Shape Memory	.01	.02	.68	.02	.00	.06	.52
Form Board	.10	.01	.11	.65	.25	.00	.82
Cube Comparison	-.02	.03	-.01	.17	.69	.04	.64
Map Planning	.22	.20	.11	-.03	.59	.06	.72
Surface Development	.62	.00	.05	.09	.25	.10	.78
Hidden Figures	.42	.27	.11	.15	.01	-.09	.44
Wiggly Block	.19	.03	-.09	.42	.01	.51	.75
% of variance	62.7	12.1	7.6	6.6	5.8	5.2	88.5 total

Factor Correlations

	Factor	1	2	3	4	5	6
	1	1.00	.23	.26	.60	.42	.31
	2	.23	1.00	.26	.11	.32	-.08
Factor	3	.26	.26	1.00	.14	.24	.37
	4	.60	.11	.14	1.00	.49	.37
	5	.42	.32	.24	.49	1.00	.29
	6	.31	-.08	.37	.37	.29	1.00

The factor correlations show a moderately strong relationship between Perceptual Speed and the Paper Folding - Surface Development Visualization factor (r=.23), Visual Memory (.27), and Spatial Orientation (.32), and little relationship between Perceptual Speed and the Form Board - Wiggly Block Visualization factor (.11), and Eidetic Memory (.01).

2. Females

Tables 5 and 6 present the factor patterns and factor correlations excluding and including Number Checking.

Without Number Checking, the factors may be interpreted as:

Factor 1 = Visualization
Factor 2 = Eidetic Memory
Factor 3 = Visual Memory
Factor 4 = Another Visualization factor (similar to the Spatial Orientation factor for males)
Factor 5 = Flexibility of Closure

With Number Checking, a Perceptual Speed factor emerges (factor two in Table 6), once again with moderate loadings for Hidden Figures and Map Planning. Paper Folding, Wiggly Block, and Surface Development all have negative loadings on this factor. The identification of the other five factors remains the same, although there is considerable change in some of the factor loadings. The Paper Folding - Surface Development Visualization factor becomes somewhat less clear-cut; the loading for the clearest marker, Paper Folding, goes down from .77 to .62, while loadings for other tests increase moderately (e.g. Map Planning, from .09 to .30). The Form Board - Wiggly Block Visualization factor becomes somewhat more clearcut, with an increase in Wiggly Block's loading from .37 to .63. Likewise, the clearest marker for the Visual Memory factor, Shape Memory, increases its loading from .55 to .74.

The highest Perceptual Speed factor correlation is with Visual Memory (r=.31), followed by Flexibility of Closure (.20), the Paper Folding - Surface Development Visualization factor (.18), the Form Board - Wiggly Block Visualization factor (.13), and Eidetic Memory (.06).

Discussion

The results support the identification of Perceptual Speed as a differentiating factor between performance and paper-and-pencil measures of spatial ability. The difference can be seen most clearly in the correlations listed in Table 2; the paper-and-pencil tests uniformly correlate more highly than the performance tests with Number Checking, both for males and for females. The highest correlations are with Map Planning, a measure of Spatial Scanning, and Hidden Figures, a measure of Flexibility of Closure.

The relationship between Perceptual Speed and Flexibility of Closure has been noted before:

> It is possible that P is analogous to flexibility of closure (restructuring closure) except for the disembedding aspect of the closure factor. In both cases the subject must hold a "model figure" in mind to compare with other figural material.
>
> (Ekstrom, 1973, p.47)

Table 5

Factor Pattern and Factor Correlations of
Spatial Tests for Females with Perceptual Speed Factor Excluded

Factor Pattern

Variable	Factor 1	2	3	4	5	h^2
Object Observation	.06	.68	.14	-.01	-.04	.55
Paper Folding	.77	.07	-.08	.05	.10	.82
Shape Memory	-.01	.19	.55	.09	.11	.48
Form Board	.23	.02	.03	.63	.11	.79
Cube Comparison	.25	-.10	.06	.34	.17	.41
Map Planning	.09	.14	.20	.43	.08	.46
Surface Development	.65	.10	.10	.14	.16	.85
Hidden Figures	.06	-.04	.05	-.00	.83	.76
Wiggly Block	.18	.41	-.37	.37	.21	.78
% of variance	70.2	9.6	8.9	5.7	5.6	86.7 total

Factor Correlations

		Factor 1	2	3	4	5
	1	1.00	.33	-.00	.70	.62
	2	.33	1.00	.29	.37	.14
Factor	3	-.00	.29	1.00	.17	.17
	4	.70	.37	.17	1.00	.56
	5	.62	.14	.17	.56	1.00

Table 6

Factor Pattern and Factor Correlations of
Spatial Tests for Females with Perceptual Speed Factor Included

Factor Pattern

Variable	Factor 1	2	3	4	5	6	h^2
Number Checking	-.02	.69	.04	-.04	.07	.00	.50
Object Observation	.01	.07	.68	.04	-.04	.13	.57
Paper Folding	.62	-.11	.15	.11	.28	-.07	.80
Shape Memory	-.02	-.01	.10	.02	.05	.74	.60
Form Board	.31	.05	-.07	.56	.04	.22	.80
Cube Comparison	.43	.15	-.07	.19	.07	-.03	.43
Map Planning	.30	.28	.14	.26	-.10	.17	.52
Surface Development	.61	-.08	.15	.10	.27	.14	.86
Hidden Figures	.09	.25	-.12	.10	.64	.14	.77
Wiggly Block	.04	-.12	.29	.63	.25	.11	.80
% of variance	64.7	10.4	9.2	5.8	5.2	4.7	88.9 total

Factor Correlations

	Factor	1	2	3	4	5	6
	1	1.00	.18	.22	.70	.49	.27
	2	.18	1.00	.07	.13	.20	.31
Factor	3	.22	.07	1.00	.34	.07	.35
	4	.70	.13	.34	1.00	.44	.21
	5	.49	.20	.07	.44	1.00	.17
	6	.27	.31	.35	.21	.17	1.00

In this case, the size of the correlation would seem to be due to the nature of the Hidden Figures task itself, not the way in which it is measured.

Spatial Scanning appears to be somewhat analogous to Perceptual Speed as well. Ekstrom et al. (1976) define this factor as: "Speed in exploring visually a wide or complicated spatial field" (p.155), which would seem to be reasonably similar to moving one's eyes quickly across the page to compare numbers.

The correlations with Cube Comparison might also be interpretable apart from its paper-and-pencil format. Ekstrom et al. (1976) note that "spatial orientation may be a more difficult or less practiced aspect of perceptual speed" (p.149). This interpretation is related to a hypothesis offered by Zimmerman (1954) and supported in part by Werdelin and Stjernberg (1969) that P will correlate more highly with easier versions of a test. As the difficulty of the test is increased, other factors begin to be measured, and the correlation with P decreases. The present study can neither support nor refute this hypothesis. The trend of the correlations in Table 2 suggests, however, that the paper-and-pencil format of spatial tests does increase their relationship with Perceptual Speed, apart from the ease or difficulty of the test, or individual characteristics of the particular type of spatial factor that is being measured.

One possible influencing factor on the correlation of Number Checking with paper-and-pencil tests is reading speed. Reading speed shows a moderate correlation with Number Checking (r=.31, Bowker, Note 1). Although liberal time limits were set for the reading of the instructions, it is possible that particularly slow readers did not finish, and thus had an incomplete understanding of the task.

The factor analysis for males shows that the addition of P has little effect on the factor structure or the factor correlations. For females, the addition of P tended to make the Paper Folding - Surface Development Vz factor less clear, and the Form Board - Wiggly Block Vz factor more clear. For both males and females, P had a higher correlation with the Paper Folding - Surface Development Vz factor than with the Form Board - Wiggly Block Vz factor.

Conclusions

With regard to testing a subject's spatial ability, the results show that paper-and-pencil measures may be slightly less accurate than performance tests because of the effect of Perceptual Speed. With regard to the factor patterns, the two Visualization factors are similar in males and females. Inclusion of a Perceptual Speed factor does not change the identification of the factors, but does cause some changes in the factor loadings for females. This would suggest that Perceptual Speed would be a useful variable to include in the analysis of the factor structure of spatial tests for females.

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Appendix

Correlation Matrices Used in the Factor Analyses

The following abbreviations are used in these matrices:

Number Checking =	NC
Object Observation =	OO
Paper Folding =	PF
Shape Memory =	SM
Form Board =	FB
Cube Comparison =	CC
Map Planning =	MP
Surface Development =	SD
Hidden Figures =	HG
Wiggly Block =	WB

The correlations have been corrected for unreliability.

Males

	NC	OO	PF	SM	FB	CC	MP	SD	HF	WB
NC	1.00	.04	.03	.17	.19	.22	.38	.20	.33	.06
OO	.04	1.00	.36	.32	.26	.27	.23	.29	.14	.41
PF	.03	.36	1.00	.25	.68	.43	.51	.74	.43	.69
SM	.17	.32	.25	1.00	.25	.15	.30	.27	.21	.21
FB	.19	.26	.68	.25	1.00	.60	.59	.68	.45	.66
CC	.22	.27	.43	.15	.60	1.00	.62	.53	.34	.42
MP	.38	.23	.51	.20	.59	.62	1.00	.62	.41	.45
SD	.20	.29	.74	.27	.68	.53	.62	1.00	.52	.62
HF	.33	.14	.43	.21	.45	.34	.41	.52	1.00	.32
WB	.06	.41	.69	.21	.66	.42	.45	.62	.32	1.00

Females

	NC	OO	PF	SM	FB	CC	MP	SD	HF	WB
NC	1.00	.13	.08	.18	.18	.16	.27	.11	.34	.01
OO	.13	1.00	.25	.36	.27	.13	.35	.33	.09	.36
PF	.08	.25	1.00	.16	.70	.49	.44	.81	.54	.68
SM	.18	.36	.16	1.00	.32	.14	.33	.33	.26	.14
FB	.18	.27	.70	.32	1.00	.54	.56	.75	.55	.67
CC	.16	.13	.49	.14	.54	1.00	.45	.58	.46	.44
MP	.27	.35	.44	.33	.56	.45	1.00	.55	.38	.44
SD	.11	.33	.81	.33	.75	.58	.55	1.00	.60	.69
HF	.34	.09	.54	.26	.55	.43	.38	.60	1.00	.45
WB	.01	.36	.68	.14	.67	.44	.44	.69	.45	1.00